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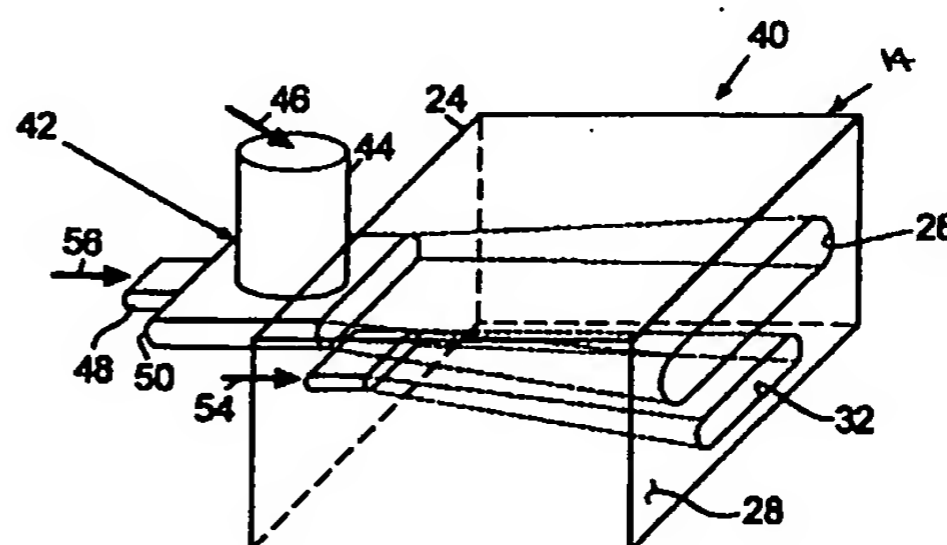
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**(54) Method and apparatus for backing-up oxy-fuel combustion with air-fuel combustion**

(57) An air-fuel burner (42) is used to maintain an operating temperature in a furnace normally heated with an oxy-fuel burner when the supply of oxygen is temporally reduced or stopped. Preferably, both the oxy-fuel burner and the air-fuel burner mount to a common pre-combustor (14) having a first passage (26) and a separate second passage (32) disposed beneath and coextensive with the first passage (26). When using the oxy-fuel burner, the oxy-fuel flame is directed through the first passage (26) and additional oxygen is directed through the second passage. When using the air-fuel burner, air or oxygen-enriched air is directed through the first passage (26) and fuel is separately directed through the second passage (32). Water cooling of the furnace gases can be used to reduce the volume of exhaust gases when operating with the air-fuel burner.



**FIG. 3**

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## Description

[0001] The present invention pertains to oxy-fuel methods and devices for producing elevated temperatures in industrial melting furnaces for such diverse products as, for example, metals, glass, and ceramic materials. In particular, the present invention pertains to combustion and methods and apparatus for continuation of combustion in the event of curtailed or terminated availability of oxygen for the oxy-fuel process.

[0002] Use of oxy-fuel burners in industrial processes such as glass melting, permits the furnace designer to achieve varying flame momentum, glass melt coverage, and flame radiation characteristics. Examples of such burners and combustion processes are described in US-A-5,256,058, US-A-5,346,390, US-A-5,547,368, and US-A-5,575,637.

[0003] One particularly effective process and apparatus for utilising oxy-fuel combustion in the manufacture of glass concerns staged combustion, which is disclosed in US-A-5,611,682.

[0004] In the beginning of the 1990s, glass manufacturers began converting furnaces from air-fuel combustion to oxy-fuel combustion. Oxygen enrichment of some air-fuel systems has been accomplished where the oxygen concentration is increased up to 30%. Higher oxygen concentrations in the range of 40-80% are not usually used because of the increased potential for forming NO<sub>x</sub> pollutants. It has also been found that using oxy-fuel combustion where oxygen is present in a concentration of between 90-100% results in more favourable economics for the user.

[0005] As used herein, the term "air" is used to mean air or oxygen-enriched air containing 22% to 80% by volume oxygen unless a more limited meaning is clear from the context. Similarly, the term "oxy-fuel combustion" is used to mean combustion with 80% to 100% by volume oxygen unless a more limited meaning is clear from the context. The term "pre-combustor" used herein includes burner blocks again unless a more limited meaning is clear from the context..

[0006] Many of the larger oxy-fuel glass furnaces are supplied by oxygen generated on site using well-known cryogenic or vacuum swing adsorption techniques. The customary and, to date, the only method for backing up the supply of on-site generated oxygen is to keep an inventory of liquid oxygen at the same site. Thus, when the on-site generation facility is taken off-line either due to a process problem or for routine maintenance, the inventory of liquid oxygen is utilised to supply the oxygen for the oxy-fuel combustion. This method of backing up the on-site generated oxygen requires large insulated tanks for storage of the oxygen in liquid form and vaporisers to enable the liquid oxygen to be converted into gaseous oxygen for use in the oxy-fuel process. It is conventional to utilise trucks to haul liquid oxygen to the site from a larger air separation facility. Utilising liquid oxygen back-up with an on-site generated oxygen system permits the user to continue using an oxy-fuel process without interruption. Any oxy-fuel combustion system, e.g. one of those disclosed in the above-referenced patents, would benefit from on-site production having a back-up system.

[0007] Until now, backing up oxy-fuel glass furnaces with an inventory of liquid oxygen has not been considered to be a problem. However, with the conversion of more and more furnaces at multi-furnace sites and the use of oxy-fuel combustion in flat or float glass furnaces which are much larger and use more oxygen, liquid oxygen backup becomes a significant concern to the user because of the high capital cost of storage tanks and vaporisers. In addition to the cost issue, a logistics problem arises relating to the transportation of the liquid oxygen to the site and having enough liquid oxygen available on short notice from a nearby air separation facility used to produce the liquid oxygen. Transportation of liquid oxygen to user sites in remote locations become even a greater problem fraught with greater difficulties.

[0008] Normally, when a glass furnace is converted from air-fuel to oxy-fuel, heat recovery devices such as regenerators and air supply systems are removed. For the user, one of the incentives to convert to oxy-fuel is reduced capital costs due to elimination of the heat recovery devices. Due to the design of oxy-fuel burners, the furnace cannot be operated by simply substituting air for oxygen in conventional combustion systems in use today. The pressure requirement to provide an equivalent amount of contained oxygen using air in an oxy-fuel burner would be extremely high, requiring an expensive air supply system. Further, some oxy-fuel burners would be sonic flow limited if fired at an equivalent firing rate.

[0009] When using oxy-fuel combustion where the oxygen supply is curtailed or disrupted, the conventional technique is to maintain the furnaces in a condition called "hot hold". Hot hold is a condition where production is stopped and the furnace is kept hot so that the glass does not solidify. Allowing the glass to solidify would severely damage the furnace. Several companies specialise in furnace heat-ups following cold furnace repairs. They use specially designed air-fuel burners to provide the initial increase in temperature in the furnace. In case of oxygen supply disruption, the same burners could be used to provide enough heating for hot hold. In this procedure, no special temperature profile for production would be attempted and the maximum temperature achieved by these devices could be about 2200°F (1205°C). This temperature is not sufficient for production of glass and is the least preferred option to be used by glass manufacturers. The cost of not producing glass is very high to the glass manufacturer, in terms of lost product sales as well as disruption of downstream glass forming lines.

[0010] Therefore, there is a definite need to provide a method and apparatus for maintaining production in a furnace used for glass manufacturing in the event of a curtailment or disruption in the availability of oxygen.

[0011] The present invention pertains to a method and apparatus to backup an oxy-fuel combustion system with an

air-fuel combustion system that can be used with or without oxygen enrichment to maintain production in an industrial furnace such as a glass melting furnace. According to the present invention, a system has been devised which permits operation in both an oxy-fuel mode and an air-fuel mode. The burner according to the present invention preferably has a unique feature relating to operation at very low velocity for the oxy-fuel mode permitting acceptable pressure drops through the burner when operating in an air-fuel mode. A burner according to the present invention can utilise oxygen enrichment to effect the process.

**[0012]** In one aspect, the present invention provides a process for maintaining heating of a furnace to an elevated temperature using oxy-fuel combustion, wherein an oxy-fuel flame is introduced into the furnace, when oxygen supply for the flame is interrupted or reduced comprising the steps of:

introducing an air stream selected from air and oxygen-enriched air containing 22% to 80% by volume oxygen into the furnace at a rate to maintain approximately the same burner firing rate as the oxy-fuel combustion; and introducing a separate fuel stream into the furnace to provide air-fuel combustion maintaining said temperature in the furnace.

**[0013]** According to the present invention, a conventional pre-combustor such as described in US-A-5,611,682 can be used for either oxy-fuel or air-fuel combustion, allowing the combustion system to be rapidly converted between the two modes. When a problem with oxygen supply occurs, the oxy-fuel burners would be turned off, disconnected, and replaced by air-fuel backup burners that have the same configuration for a connection to the pre-combustor. With the air-fuel backup system, the user would retain the air supply systems from previous air-fuel systems used in the melting operation or, air blowers would be supplied as part of the back up system. Air fuel burners according to the present invention should be capable of firing at rates substantially higher than the oxy-fuel burners.

**[0014]** Thus, in a preferred embodiment, the present invention is a process for maintaining heating of a furnace to an elevated temperature using oxy-fuel combustion, wherein a flame is introduced into the furnace and an oxidiser stream is introduced underneath said flame, when oxygen supply for said flame and the oxidiser stream is interrupted or reduced comprising the steps of replacing the flame with an air stream selected from air and oxygen-enriched air containing 22% to 80% by volume oxygen introduced at a rate to maintain approximately the burner firing rate when oxygen is the only source of oxidant for combustion, and replacing the oxidiser stream introduced underneath said flame with a separate fuel to provide air-fuel combustion maintaining said temperature in the furnace.

**[0015]** In another aspect, the present invention is a combustion system of the type having an oxy-fuel burner adapted to produce a flame with a pre-combustor mounted on the burner, said pre-combustor having a first passage with an inlet at a burner end of the pre-combustor, said inlet being in fluid tight relation to a flame end of the burner, and an outlet at a discharge end of the pre-combustor, said outlet being adapted to direct the flame produced by the burner for heating in industrial environments in a generally flat fan like configuration, and a second separate passage in the pre-combustor disposed beneath and coextensive with the first passage, said second passage terminating in a nozzle end in the discharge end of the pre-combustor to direct oxidising fluid underneath and generally parallel to the flame, characterised in that the system further comprises air supply means to introduce one of air or oxygen-enriched air through the burner into the first passage of the pre-combustor in place of the flame, and fuel supply means to introduce fuel into the second separate passage in the pre-combustor in place of the oxidising fluid, whereby the combustion system can continue to heat the industrial environment in the event supply of oxygen is interrupted or reduced.

**[0016]** Usually, the pre-combustor is between 4 and 18 inches (19 and 45 cm) in length. Preferably, the first passage and the second passage each have a width to height ratio of between 5 and 30 at the discharge end of the pre-combustor and the width of the passages are disposed at an angle between -15° to +30°, especially 0 to +15°, on either side of a central vertical plane through the pre-combustor.

**[0017]** In yet another aspect, the present invention contemplates reducing exhaust gas volume in a furnace being heated according to the aforementioned method and apparatus of the invention by liquid water cooling of the exhaust gases exiting the furnace.

**[0018]** In still another aspect, the present invention pertains to substitution of air-fuel combustion for oxy-fuel combustion to maintain heating in an industrial environment, the air or oxygen-enriched air for the air-fuel combustion being introduced into the environment in any manner so there is sufficient volume to effect the required level of heating. In this aspect water cooling of the exhaust gases will be beneficial for lowering exhaust gas volume.

**[0019]** The present invention pertains to a method and apparatus to back-up an oxy-fuel heating system with an air-fuel heating system. According to the invention, the back-up air-fuel system can be operated with or without oxygen enrichment of the air. The burner according to the invention permits at least two distinct modes of operation, i.e. oxy-fuel and air-fuel. A preferred feature of the burner is the operation at very low velocity for the oxy-fuel mode, thus permitting acceptable pressure drops through the burner when operating in the air-fuel mode.

**[0020]** The same pre-combustor can be used during either oxy-fuel or air-fuel operation, allowing the combustion system to be rapidly converted from one mode to the other. In the case where an operator encounters a problem with

the oxygen supply, the oxy-fuel burners would be turned off, disconnected, and replaced with air-fuel back-up burners that have the same connection to the pre-combustor. With an air-fuel back-up system, a glass manufacturer could retain its air supply systems present before conversion to oxy-fuel combustion, or blowers would be supplied as part of the back-up system. It is important that the air-fuel back-up burners are capable of firing at a rate substantially higher than that of the oxy-fuel burners being backed-up.

[0021] Higher firing rate for the back-up air-fuel burner is required because of the additional energy losses caused by heating and expelling nitrogen. Furthermore, the air used for combustion in a back-up system will typically not be pre-heated which results in a decrease in furnace efficiency relative to a typical air-fuel furnace. A simplified thermodynamic calculation illustrates the need to increase the fuel firing rate when non preheated air is used for combustion. The assumptions for this example are: fuel and oxygen completely react with no excess oxygen and no intermediate products remaining; all gases (e.g. methane, air, or oxygen) enter the furnace at 77°F (25°C); and, all gases exhaust the furnace at 2800°F (1540°C) after complete combustion. Under these conditions, 2.65 times the firing rate is required when firing with air as compared to firing with 100% oxygen in order to maintain the same available heat. Available heat is the energy transferred to the charge and for heat loss from the furnace.

[0022] Thus, the total oxidant volumetric flow rate will increase dramatically as the oxygen flow rate is reduced. The volume of the oxidant stream is increased by a factor of 4.76 because of the addition of nitrogen and an additional 2.65 times because of the higher firing rate requirement. This means that the flow rate of the oxidant stream is increased by about 12.6 times when air is completely substituted for oxygen.

[0023] A major concern with using air-fuel combustion in an oxy-fuel burner assembly is the air supply pressure required to accommodate the higher gas volumes needed. The present invention preferably utilises a low velocity oxidiser system. Thus, even when firing in an air-fuel mode, pressure drop is low enough to permit the use of relatively inexpensive air blowers, while maintaining burner firing rates equal to or greater than those used with oxy-fuel firing. This, in turn, allows for continuity of production when a user, e.g. a glass melter, is operating in the back-up mode during an emergency loss or curtailment of oxygen supply.

[0024] Oxy-fuel burners with oxidant velocities greater than 90 ft/s (27 m/s) at any point in the burner, design will be sonic limited at the equivalent-firing rate when air is used as the oxidant at full production. The sonic velocity is defined by the equation

$$a = \sqrt{kRT},$$

where  $k$  is the ratio of specific heats (1.4 for air),  $R$  is the gas constant (287 J/kg K), and  $T$  is the absolute temperature. For air at 77°F (25°C), the sonic velocity is 1135 ft/s (346 m/sec.). For an oxy fuel burner with an oxygen velocity of 100 ft/s (30 m/s), the equivalent flow rate using air will be 12.6 times that amount or 1260 ft/s (385 m/s) which is greater than the sonic velocity. Therefore, to avoid a sonic limit, the oxy-fuel burner must be designed with an oxygen velocity of less than 90 ft/s (27 m/s) if complete air substitution for oxygen is to be used without changing any part of the burner assembly. Alternatively, this limit can be avoided according to one aspect of the invention where the burner body is changed when switching between operating modes. The pre-combustor should be designed so that the superficial velocity is less than the sonic velocity for air-fuel operation.

[0025] The shape of the flame is also a concern for traditional oxy-fuel burners operating at 2.65 times their rated firing capacity especially with 12.6 times the volumetric flow rate through the oxidant passage(s). An embodiment of the invention disclosed below provides a suitable flame shape for both oxy-fuel and air-fuel operation.

[0026] Concerns relating to oxidant supply pressure, velocity limits, and flame shape can be overcome according to the present invention. We have found it is possible to enable a user to switch from oxy-fuel firing to air-fuel firing using the same pre-combustor while modifying the burner body of a Cleanfire® HR™ burner offered to the trade by Air Products and Chemicals Inc. of Allentown Pennsylvania.

[0027] The following is a description by way of example only and with reference to the accompanying drawings of a presently preferred embodiment of the invention. In the drawings:

Figure 1 is a schematic perspective view of a conventional staged oxy-fuel combustion apparatus;

Figure 2 is a view taken along line 2-2 of Figure 1;

Figure 3 is a schematic perspective view of an apparatus according to the present invention;

Figure 4 is a front view of the pre-combustor of the apparatus of Figure 3;

Figure 5 is a plot of normalised methane flow rate against normalised oxygen flow rate for conditions from zero production to full production;

Figure 6 is a plot of oxygen concentration against normalised oxygen flow rate for the production rates of Figure 5;

Figure 7 is a plot of normalised exhaust gas flow rate against normalised oxygen flow rate for several production rates;

Figure 8 is a plot of normalised exhaust gas flow rate after dilution with air against oxygen flow rate for production

rates between zero and full production; and

Figure 9 is a plot of normalised exhaust flow rate after dilution with water against normalised oxygen flow rate for furnace production from zero to full production.

5 [0028] Referring to Figure 1, a staged combustion apparatus 10 includes an oxy-fuel burner 12 and a pre-combustor 14. The oxy-fuel burner 12 includes a central conduit 16 for receiving a fuel such as natural gas, which is indicated by arrow 18. A source of oxygen indicated by arrow 20 is introduced into a passage that is between the fuel conduit 16 and an outer concentric conduit 22. The burner is described in detail in US-A-5,611,682. The flame end of the burner 12 is fitted to a burner end 28 of the pre-combustor 14 and held in fluid tight relationship thereto. The pre-combustor 14  
10 contains a first or central passage 26, which extends from the burner end 24 to a discharge end 28 of the pre-combustor 14. The passage 26 has a width greater than the height and has a diverging shape as shown and as described in US-A-5,611,682. In order to have stage combustion, staging oxygen represented by arrow 30 is introduced into a second passage 32 in the pre-combustor 14. The passage 32 has a shape complimentary to that of the central passage 26 and also has a greater width than height as illustrated and again as described in detail in US-A-5,611,682.

15 [0029] Referring to Figure 2, at the burner end 24 of the pre-combustor 14 the oxy-fuel burner 12 has a discharge end with a central fuel conduit 16 surrounded by an oxygen passage 22. The staging oxygen exits a passage 31 that is disposed below the conduit 16 for the oxy-fuel flame as shown in Figure 2.

[0030] Figure 3 shows a combustion apparatus according to the present invention. The combustion apparatus 40 includes a pre-combustor 14, which is identical to the pre-combustor 14 of Figure 1. According to the present invention,  
20 the burner 42 is similar to the oxy-fuel burner 12 of Figure 1 with a device 44 to permit introduction of air (or oxygen-enriched air) into an upper passage 50 of burner 42. The burner 42 is also adapted to introduce air by passage 48 of burner 42 into the upper passage 50 where oxidant from passages 44 and 48 are mixed. Arrow 46 represents introduction of air into the device 44 which in turn introduces the air into the passage 50. Arrow 56 represents introduction of air into the passage 48. The air moves from passage 50 into the central passage 26 of the pre-combustor and exits to the  
25 furnace.

[0031] When the burner is converted from oxy-fuel to air-fuel firing, the supply of staging oxygen (indicated by arrow 30 in Figure 1) is replaced by fuel, represented by arrow 54, so that fuel, which can be oxygen-enriched, exits passage 32 of the pre-combustor 14. Shown schematically in Figure 4 are the passages 26 and 32 at the front end of the pre-combustor 14 with passage 26 being used to introduce air into the furnace and passage 32 being used to introduce fuel  
30 into the furnace. When the burner 42 is used in the air-fuel firing mode, the air flows through passage 26 and the fuel flows through the passage 32. The pre-combustor design is such that a stable air-fuel flame is established because of the re-circulation region between the two openings.

[0032] In addition to simple air-fuel firing capability, the device of the present invention permits varying degrees of oxygen enrichment to be accomplished. Use of oxygen enrichment improves flexibility during operation in the backup  
35 mode by decreasing the use of oxygen supplied from liquid oxygen storage. It also permits adjustment of the flame length by adding oxygen to the air flow.

[0033] Supplemental oxygen can be supplied by various methods. For example the air can be enriched with oxygen, oxygen lances could be supplied through either or both the primary passage 26 of pre-combustor 14 or the staging port 32, or separate oxygen lances could be installed at a distance away from the pre-combustor 14 or staging port 32.  
40 Oxygen introduced through the staging port with the natural gas could provide means to create soot for better radiation heat transfer to the furnace charge.

[0034] Using the method and apparatus of the present invention makes it possible to maintain maximum temperature and temperature distribution needed for glass production. Oxygen enrichment or oxy-fuel firing, preferably should be used on burners with the highest firing rates near the hot spot in the furnace. This will reduce the flow rate of air  
45 needed for these burners and reduce the pressure drop. Also, oxygen enrichment increases the peak flame temperature and thereby increases heat transfers in the hot spot. It is well known that a hot spot is required in glass making furnaces to established proper convection cells in the glass melt which are required to produce glass of acceptable quality.

[0035] Whereas other air-fuel technologies can be used to maintain hot hold conditions, the present invention is intended to permit the user to continue production. The minimum firing rate provided by the air-fuel backup system usually is such that at least 20% of the design production rate can be maintained. It is believed that this production rate is  
50 sufficient to allow a float glass producer to maintain a continuous glass ribbon in the float bath.

[0036] Higher velocity oxy-fuel burners could be modified for low velocity operation by adding one or more inlet ports to use the technology disclosed herein. These inlets could be normally closed or used for staging during oxy-fuel operation. Also, one or more additional inlet ports could be added on-the-fly prior to commencing air-fuel backup by  
55 drilling a hole in the refractory wall in a location close to the burner port.

[0037] Another alternative for furnaces using high velocity burners is to replace the pre-combustors with blocks having larger openings to reduce the pressure drop. With this method there is the danger of introducing foreign refractory material into the glass melt during the replacement procedure which could cause glass defects. Furthermore,

replacement of pre-combustors on the fly requires substantial time, possibly too long to avoid interruption of production.

[0038] Figure 5 shows the methane flow rate required for hot hold conditions (zero production rate; dashed line), 20% (dotted line), 50% (dot-dashed line) and full production (continuous line) conditions, assuming, for example, that 35% of the available heat is required for furnace wall heat losses under full production conditions. Hot hold could be achieved at lower firing rates than the plot shows since the overall furnace temperature would be lowered thereby reducing the wall heat losses. This plot assumes that the heat losses remain the same, independent of production rate or oxygen usage. The methane flow rate is normalised based on the methane flow rate for full production with 100% oxy-fuel, and the oxygen flow rate is normalised based on the oxygen flow rate for full production with 100% oxy-fuel. The normalised oxygen flow rate is 1.0 when all of the oxidant for combustion is supplied by the oxygen source (no air) and zero when all of the oxidant for combustion is supplied by air.

[0039] Figure 6 is a corresponding plot of oxygen concentration as a function of normalised oxygen flow rate for each of the production rates shown in Figure 5.

[0040] As indicated by point A in Figure 5, hot hold using only air as the oxidant for combustion (zero normalised oxygen flow rate), the methane flow rate is about the same as required for 100% oxy-fuel at full production (normalised value equal to 1). Hot hold could also be maintained at 35% of the full production oxygen flow rate with 35% of the full production methane flow rate (point B). Referring to Figure 6 (point B), the operating condition represented by point B corresponds to 100% oxy-fuel with no air dilution.

[0041] Figure 5 shows that the oxygen flow rate and the methane flow rate can each be reduced by half to produce 20% of full production. This means that if production is limited to 20% of the full production rate, the stored oxygen supply can last two times longer. According to Figure 6, this corresponds to 100% oxy-fuel firing.

[0042] At 50% production, the oxygen flow rate could be reduced to half of the full production flow rate and the methane at about 95% of the full production flow rate. According to Figure 6, the oxygen concentration for this operating condition would be about 35%.

[0043] The exhaust gas temperature from an oxy-fuel furnace is higher than a corresponding air-fuel furnace after the heat recovery device. Glass manufacturers therefore must decrease the temperature of the oxy-fuel combustion products by some method before the gases enter the sections of the flue system fabricated with metal. Because of current air pollution regulations, fuel gas treatment for glass furnaces typically include particulate removal devices, such as electrostatic precipitators or bag houses. These devices have a maximum operating temperature significantly lower than the oxy-fuel furnace exhaust temperature, typically around 1000°F (540°C). Therefore, exhaust gases must be cooled by cold (ambient) dilution air before these devices.

[0044] If air is substituted for oxygen for combustion in a furnace designed for oxy-fuel combustion, the exhaust volume will be increased substantially. Figure 7 shows how the exhaust flow rate increases as air is substituted for oxygen for several production rates. The same assumptions regarding inlet and outlet temperatures and heat losses used for the previous figures are used to generate this figure. The exhaust flow rate is normalised with respect to the exhaust flow rate for full production with 100% oxy-fuel. For full production, the exhaust flow rate will be increased by more than nine times if oxygen is completely replaced by air. More than three times the exhaust flow rate can be expected at hot hold conditions where air completely replaces oxygen.

[0045] As a result of the increased flow of hot exhaust gases, much more dilution air must be provided to decrease the temperature to the same level before the gases enter the metal section of the flue system. Figure 8 shows the result of thermodynamic calculations where furnace exhaust gases at 2800°F (1540°C) are diluted with air at 77°F (25°C) to produce a 1000°F (540°C) gas stream which is a temperature suitable for the metal section of the flue system. The normalised exhaust flow rate after dilution with air is plotted as a function of normalised oxygen flow rate. The exhaust flow is normalised with respect to the 100% oxy-fuel, full production case where exhaust gases at 2800°F (1540°C) are diluted with air at 77°F (25°C) to produce a 1000°F (540°C) gas stream. If air is substituted for oxygen under full production conditions and the exhaust gases are diluted with air at 77°F (25°C) to produce a 1000°F (540°C) stream, the resulting exhaust gas flow rate would be greater than 7.5 times the full production oxy-fuel case. Flue systems are not capable of handling this much of an increase in throughput because of pressure drop limitations. The furnace pressure would increase, possibly leading to structural failure.

[0046] There are several ways of dealing with the increased flue gas volume: e.g., reduced production, oxygen enrichment for combustion, alternative ways of cooling the flue gases (e.g. with water), using additional flue gas exhaust capability, bypassing the flue gas treatment section, or a combination of two or more of these above methods. A preferred method of resolving the increased volume of flue gases, in accord with the present invention, is to combine water cooling, reduced production, and if necessary oxygen enrichment for combustion.

[0047] Figure 9 shows the results of a thermodynamic calculation where liquid water at 77°F (25°C) provides evaporative direct contact cooling. The normalised exhaust flow rate after dilution with water is plotted against the normalised oxygen flow rate. The exhaust flow is normalised with respect to the 100% oxy-fuel, full production case where exhaust gases at 2800°F (1540°C) are diluted with air at 77°F (25°C) to produce a 1000°F (540°C) gas stream. The figure shows that the exhaust gas volume can be reduced by 50% for full production oxy-fuel operation when water is

substituted for air as the cooling medium in the exhaust stream. For the case of full production using air instead of oxygen for combustion and water is used for cooling the exhaust gases, the exhaust flow rate is 3.6 times the base case full production, full oxy-fuel case. For 50% production using air instead of oxygen as the oxidant, the exhaust stream volume is about 2.5 times greater than the base case full production, full oxy-fuel case.

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Table 1

Summary of the backup burner and method.	
Preferred Embodiment	Alternate Embodiments
1. Oxy-fuel and air-fuel use same pre-combustor	Pre-combustor is replaced, new holes are drilled in the furnace wall, or existing holes are opened using pre-combustors predesigned for air-fuel backup.
2. Oxy-fuel and air-fuel use same mounting replaced, new hardware	Pre-combustor is replaced, new holes are drilled in the furnace wall, or existing holes are opened using pre-combustors predesigned for air-fuel backup.
3. Pre-combustor cross-section is such that the Oxidiser velocity is less than 250 ft/s (76m/s) at the velocity minimum cross-section of the pre-combustor or burner body during backup operation.	Pre-combustor cross-section is such that the oxidiser is less than 500 ft/s (152m/s) at the minimum cross-section of the pre-combustor or burner body during backup operation.
4. Air used as oxidant during backup operation	Oxygen concentration during backup operation of less than 50%.
5. Flue gas cooling with water	Flue gas cooling with a combination of water and air.
6. Oxidiser temperature less than 150°F (65°C).	Oxidiser temperature less than 1000°F (540°C).
7. No additional pre-combustors needed during air fuel backup operation	Up to two times the number of burners used for air-fuel operation as were used in oxy-fuel operation
8. More than 80% of full production capacity during air-fuel backup operation	More than 20% of full production capacity during air-fuel backup operation.
9. Superficial velocity in pre-combustor based on total cross-sectional opening less than 90 ft/s (27 m/s) for oxy-fuel operation	Superficial velocity in pre-combustor based on total cross-sectional opening less than 400 ft/s (122) for oxy-fuel operation.

[0048] Alternatives to the proposed invention are: Option 1) continued 100% oxy-fuel firing with more oxygen storage, Option 2) hot hold with air-fuel heat up burners, and Option 3) hot hold or some production with high momentum oxy-fuel burners using air instead of oxygen. The difference between the proposed invention and Option 1 is reduced use of oxygen and expense of storage of liquid oxygen. The difference between the invention and Option 2 is continued production and expense. The difference between the invention and Option 3 is the technical difficulty of supplying air with a high pressure.

[0049] The benefit of the invention compared to Option 1 is lower capital cost (fewer liquid oxygen storage tanks). Also, depending on the length of time that the on-site oxygen plant is down, the logistics and availability problems of liquid oxygen are avoided. Another benefit of the proposed invention over Option 1 is that it can function if there is a problem with the oxygen supply lines or flow control skids. A benefit of the invention compared to Option 2 is higher maximum temperature in the furnace with similar temperature profile needed for glass production. Another benefit of the invention compared to Option 2 is continued production. The most effective process is where full production is continued using air or oxygen-enriched air. Even production at a minimum level to sustain a glass ribbon in the float bath is extremely valuable. Re-establishing the glass ribbon is time consuming and could delay production by one or more days. For example, for a flat glass furnace, that produces 600 tons/day (545 tonnes/day), and with glass valued at \$300/ton (\$272/tonne), one days production is worth \$180,000. A further benefit of the invention compared to Option 2 is that the back-up system is in place. Option 2 requires that an outside company must come to the facility and install their equipment. A still further benefit of the invention is that the furnace refractory does not need to be drilled, cut, or otherwise disturbed.

[0050] The present invention provides the user the ability to use different burners for air-fuel and oxy-fuel operation, a common mounting system for air-fuel and oxy-fuel burners, higher maximum furnace temperatures compared to air-fuel heat up burners. The process of the present invention is capable of generating similar temperature distribution in a

furnace needed for glass processing, permits higher firing rates at the furnace hot spot by preferentially increasing oxygen concentration, permits use of separate but closely spaced ports for introduction air and fuel for air-fuel operation, and function change of pre-combustor/staging ports for air-fuel and oxy-fuel operation. For oxy-fuel operation, the larger opening is used as a pre-combustor with oxygen and fuel flow and the smaller opening for oxygen staging. For air-fuel operation, the larger opening is used for flowing air or oxygen-enriched air and the smaller port primarily for fuel.

[0051] It is within the scope of the present invention to have a separate pre-combustor placed in the furnace wall to introduce air or oxygen-enriched air and fuel into the furnace. In this mode the oxy-fuel burner would be turned off and the separate pre-combustor would be used to effect combustion according to the teaching of the invention.

[0052] It is also within the scope of the present invention to introduce air and fuel into the furnace through separate burners or pipes that are independent of the oxy-fuel burners, so long as the air or oxygen-enriched air and fuel are introduced in accord with the teachings of the invention.

#### Claims

1. A process for maintaining heating of a furnace to an elevated temperature using oxy-fuel combustion, wherein an oxy-fuel flame is introduced into the furnace, when oxygen supply for the flame is interrupted or reduced comprising the steps of:

introducing an air stream selected from air and oxygen-enriched air containing 22% to 80% by volume oxygen into the furnace at a rate to maintain approximately the same burner firing rate as the oxy-fuel combustion; and introducing a separate fuel stream into the furnace to provide air-fuel combustion maintaining said temperature in the furnace.

2. A process according to Claim 1, wherein during oxy-fuel combustion an oxidiser stream is introduced underneath the oxy-fuel flame and, when oxygen supply for said flame and the oxidiser stream is interrupted or reduced, the oxy-fuel flame is replaced with the air stream and the oxidiser stream is replaced with the separate fuel stream.

3. A process according to any one of the preceding claims, wherein the furnace is a glass melting furnace having several burners and, during air-fuel combustion operation, temperature distribution in the furnace is maintained by using a higher oxygen-concentration air stream air in those burners adjacent a hot spot in the furnace than in the other burners.

4. A process according to any one of the preceding claims, wherein, during the air-fuel combustion, the air stream has a flow rate (calculated as non-oxygen-enriched air) about 12.6 times greater than the oxygen flow rate during oxy-fuel combustion.

5. A process according to any one of the preceding claims, wherein the velocity of the air stream at a discharge end of the burner is less than 76 m/s (250 ft/s).

6. A process according to any one of the preceding claims, wherein the air stream and the separate fuel stream are introduced through a pre-combustor.

7. A process according to Claim 6, wherein the same pre-combustor is used for the oxy-fuel combustion and the air-fuel combustion.

8. A process according to any one of the preceding claims, wherein the separate fuel stream contains oxygen to enhance radiation heat transfer to a charge being heated in said furnace.

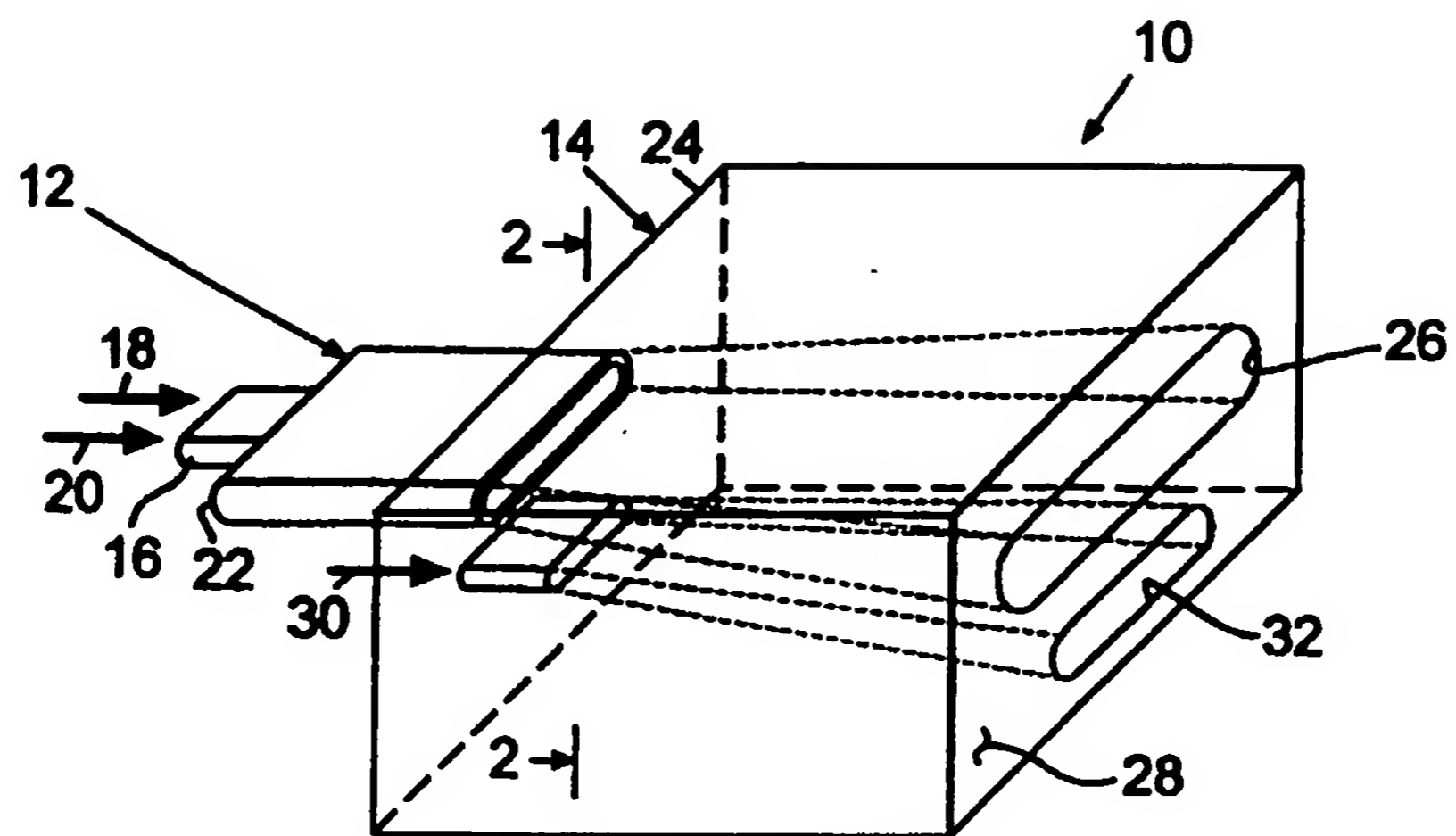
9. A process according to any one of the preceding claims, wherein exhaust gases exiting the furnace are cooled with liquid water.

10. A combustion system having an oxy-fuel burner (12) adapted to produce a flame with a pre-combustor (14) mounted on the burner (12), said pre-combustor (14) having a first passage (26) with an inlet at a burner end (24) of the pre-combustor (14), said inlet being in fluid tight relation to a flame end of the burner (12), and an outlet at a discharge end (28) of the pre-combustor (14), said outlet being adapted to direct the flame produced by the burner (12) for heating in industrial environments in a generally flat fan like configuration, and a separate second passage (32) in the pre-combustor disposed beneath and coextensive with the first passage (26), said second passage (32) terminating in a nozzle end in the discharge end (28) of the pre-combustor (14) to direct oxidising fluid underneath

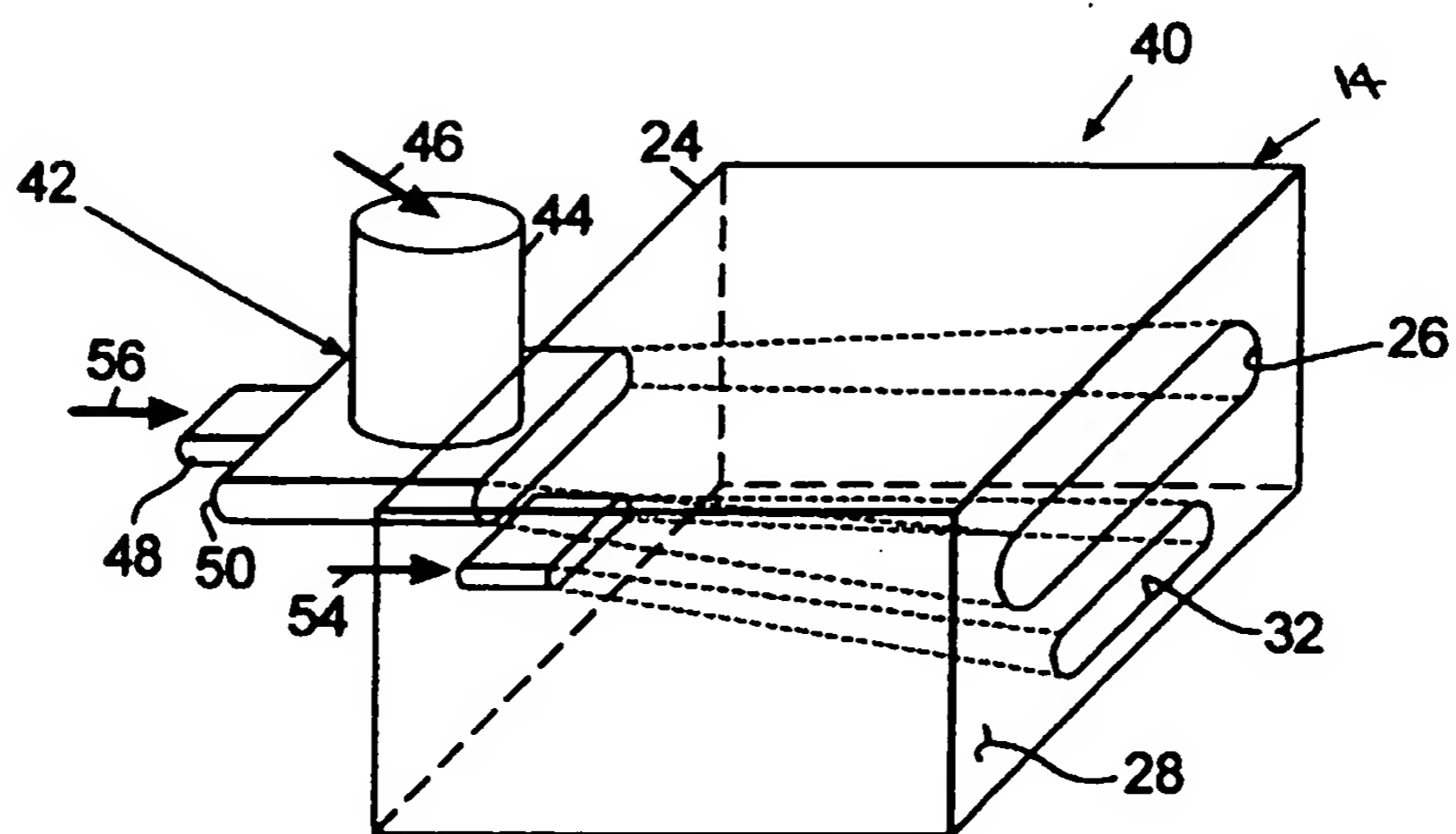
and generally parallel to the flame, characterised in that the system further comprises:

air supply means (46 & 56) to introduce air or oxygen-enriched air through the burner (12) into the first passage (26) of the pre-combustor (14) in place of said flame; and  
 fuel supply means (54) to introduce fuel into said second separate passage (32) in said pre-combustor in place of said oxidising fluid,  
 whereby said combustion system can continue to heat said industrial environment in the event supply of oxygen is interrupted or reduced.

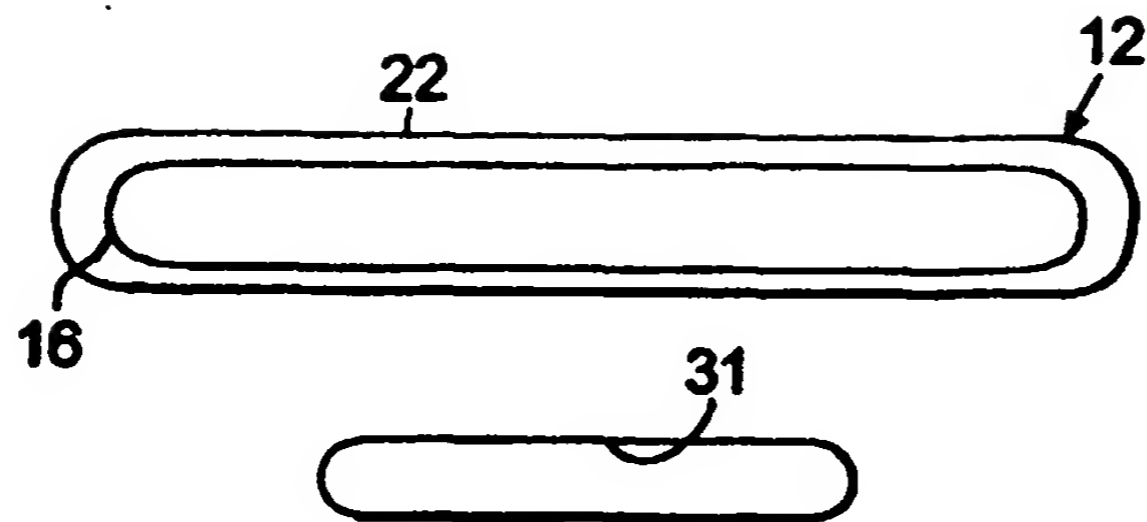
11. A system according to Claim 10, wherein said pre-combustor (14) is between 19 and 45 cm (4 and 18 inches) in length.
12. A system according to Claim 10 or Claim 11, wherein the first passage (26) and the second passage (32) each have a width to height ratio of between 5 and 30 at the discharge end of the pre-combustor (14).
13. A system according to any one of Claims 10 to 12, wherein walls defining the width of the first passage (26) and the second passage (32) are disposed at an angle between  $-15^{\circ}$  to  $+30^{\circ}$  on either side of a central vertical plane through the pre-combustor.
14. A system according to Claim 13, wherein said angle is between 0 to  $+15^{\circ}$  on either side of said vertical plane.
15. A system according to any one of Claims 10 to 14, wherein the fuel supply means (54) includes means to introduce oxygen into the fuel supplied to the pre-combustor (14).
16. A heating furnace comprising a combustion system as claimed in any one of Claims 10 to 15.
17. A furnace according to Claim 16, comprising water cooling means to water cool exhaust gases emerging from the furnace when said combustion system is in use.
18. A method of maintaining a furnace at an elevated operating temperature with or without use of an oxidant stream of predetermined minimum oxygen concentration, said method comprising, when said oxidant stream is used, heating the furnace with an oxy-fuel burner using said oxidant stream in the oxy-fuel flame at an oxygen velocity of less than 27 m/s (90 ft/s) and, when said oxidant stream is not used, heating the furnace with an air-fuel burner of substantially higher firing rate than the oxy-fuel burner.
19. A method according to Claim 18, wherein in the air-fuel burner mode, the furnace is heated as defined in any one of Claims 2 to 9.
20. A method according to Claim 19, wherein the furnace is heated by a combustion system as defined in any one of Claims 10 to 15.
21. The use of an air-fuel burner to maintain an operating temperature in a furnace heated by oxy-fuel burner during interruption of oxygen supply to the oxy-fuel burner.
22. A use according to Claim 21, wherein the furnace is heated by a combustion system as defined in any one of claims 10 to 15.



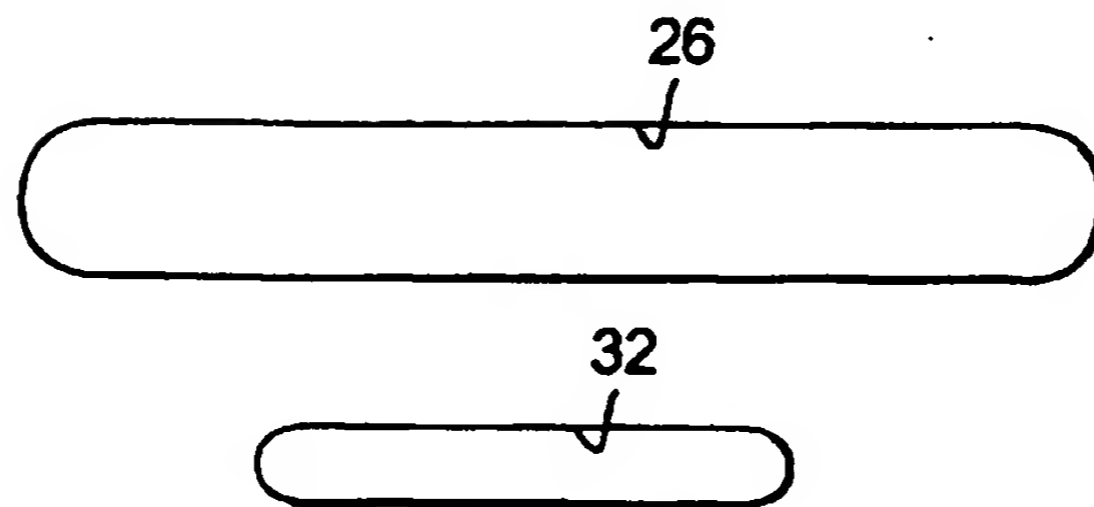
**FIG. 1**



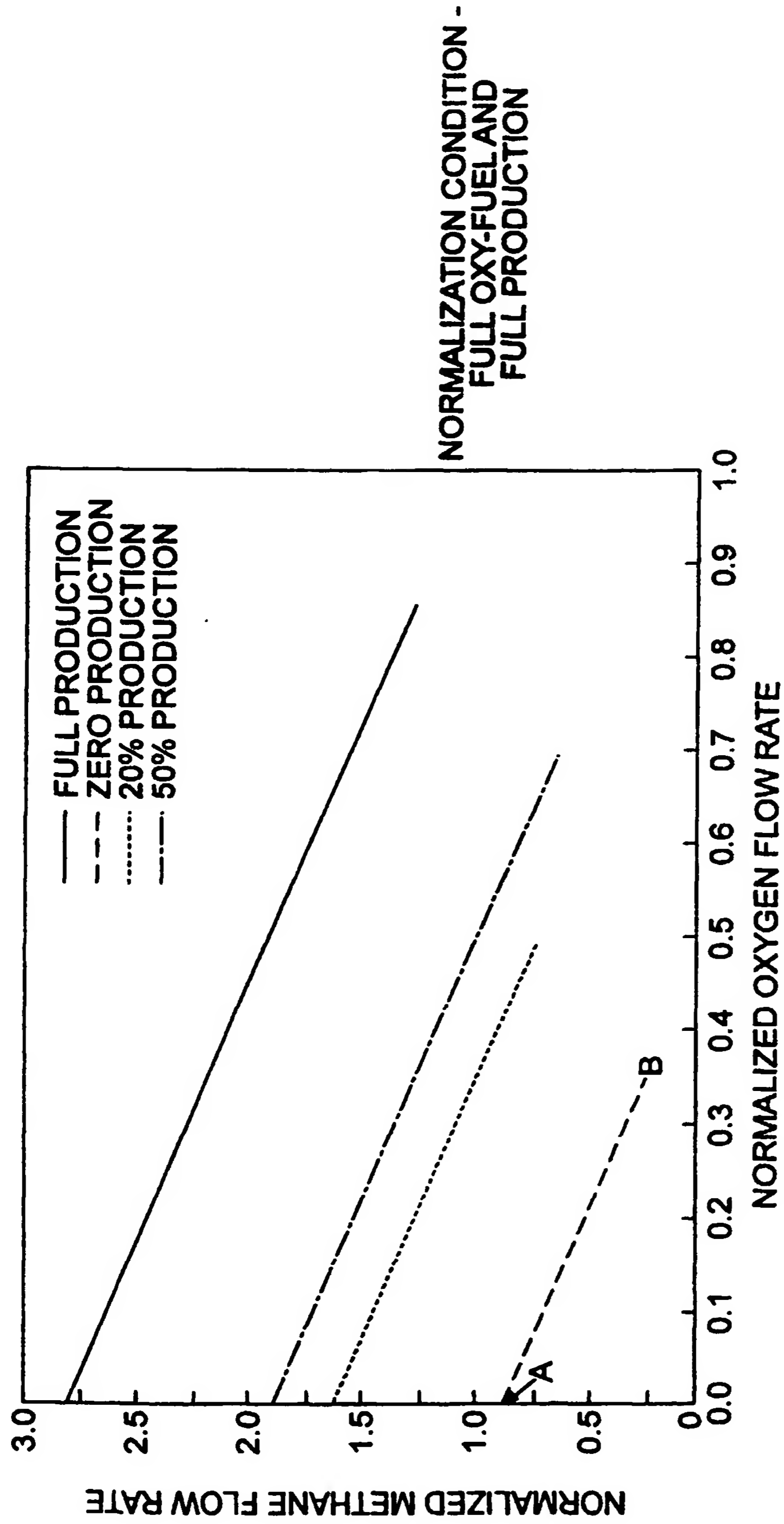
**FIG. 3**



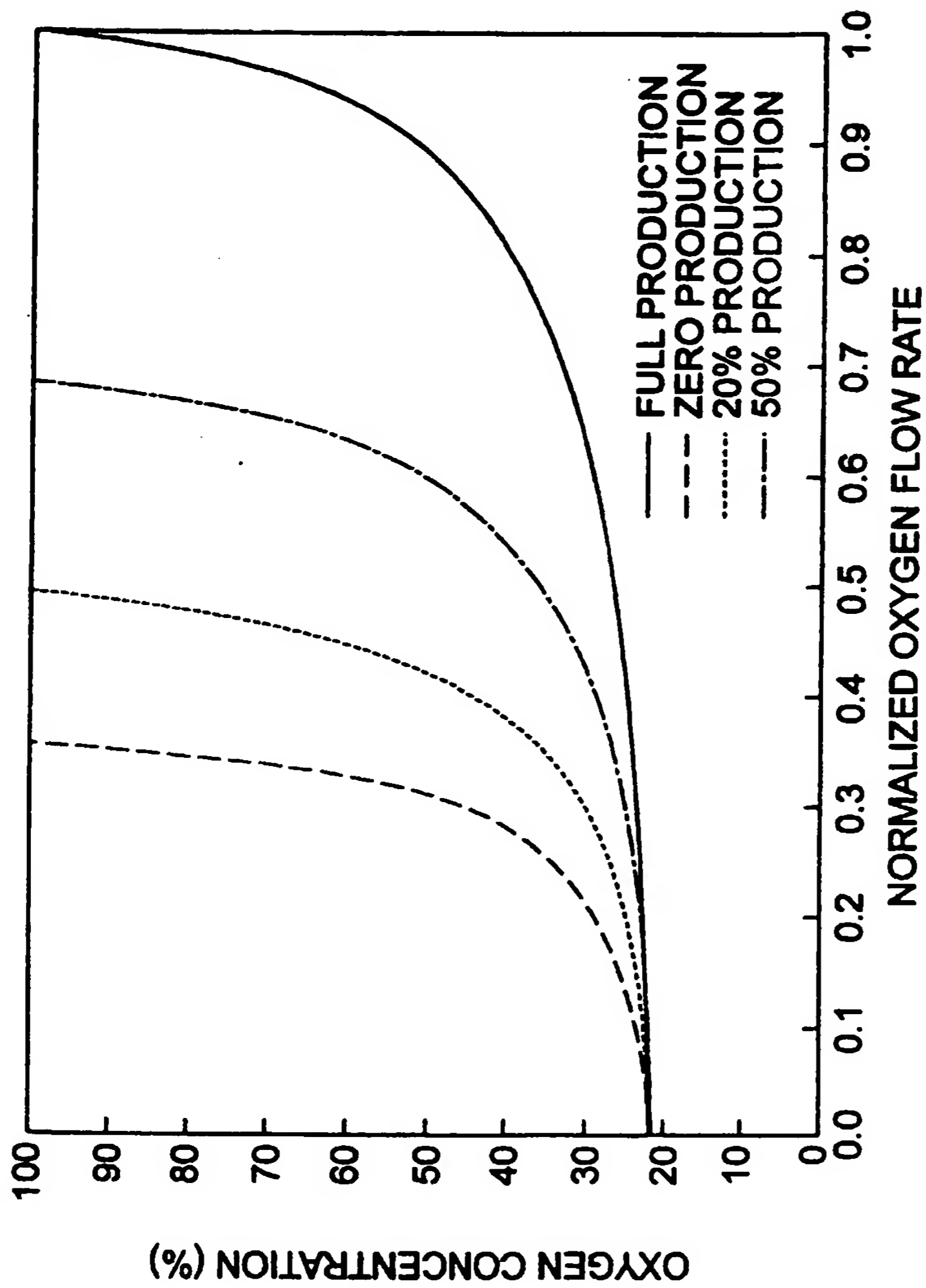
**FIG. 2**



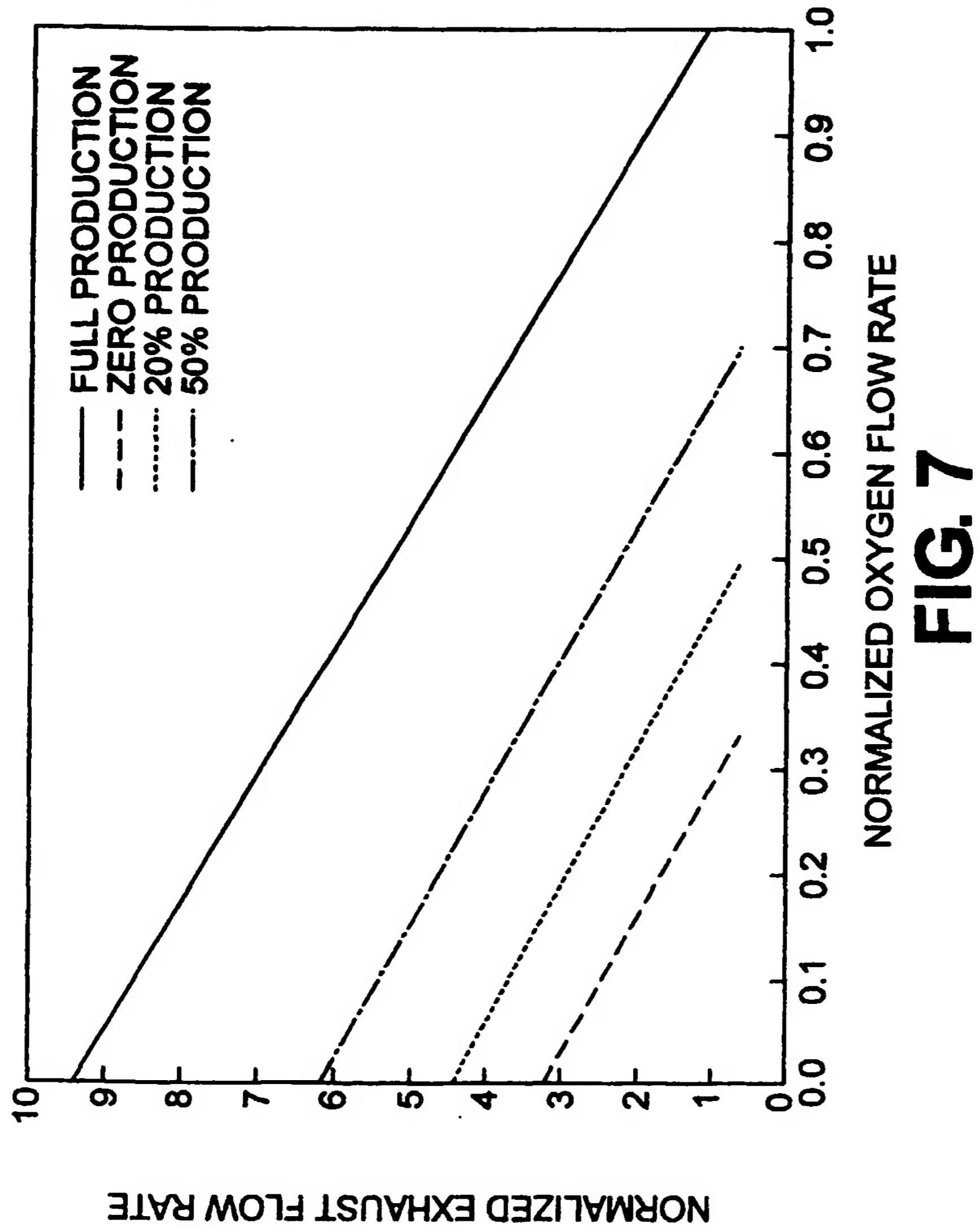
**FIG. 4**



**FIG. 5**



**FIG. 6**



**FIG. 7**

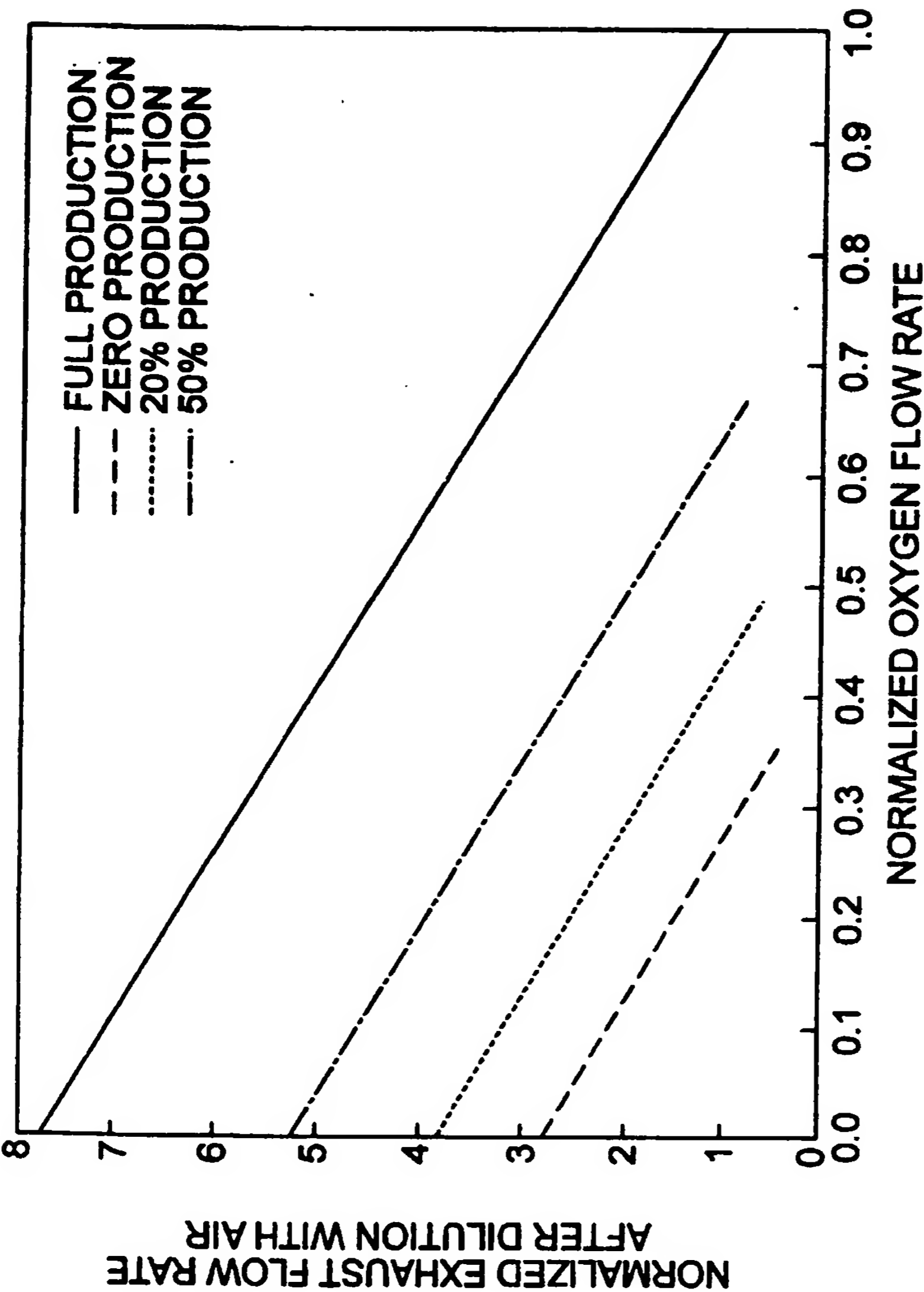
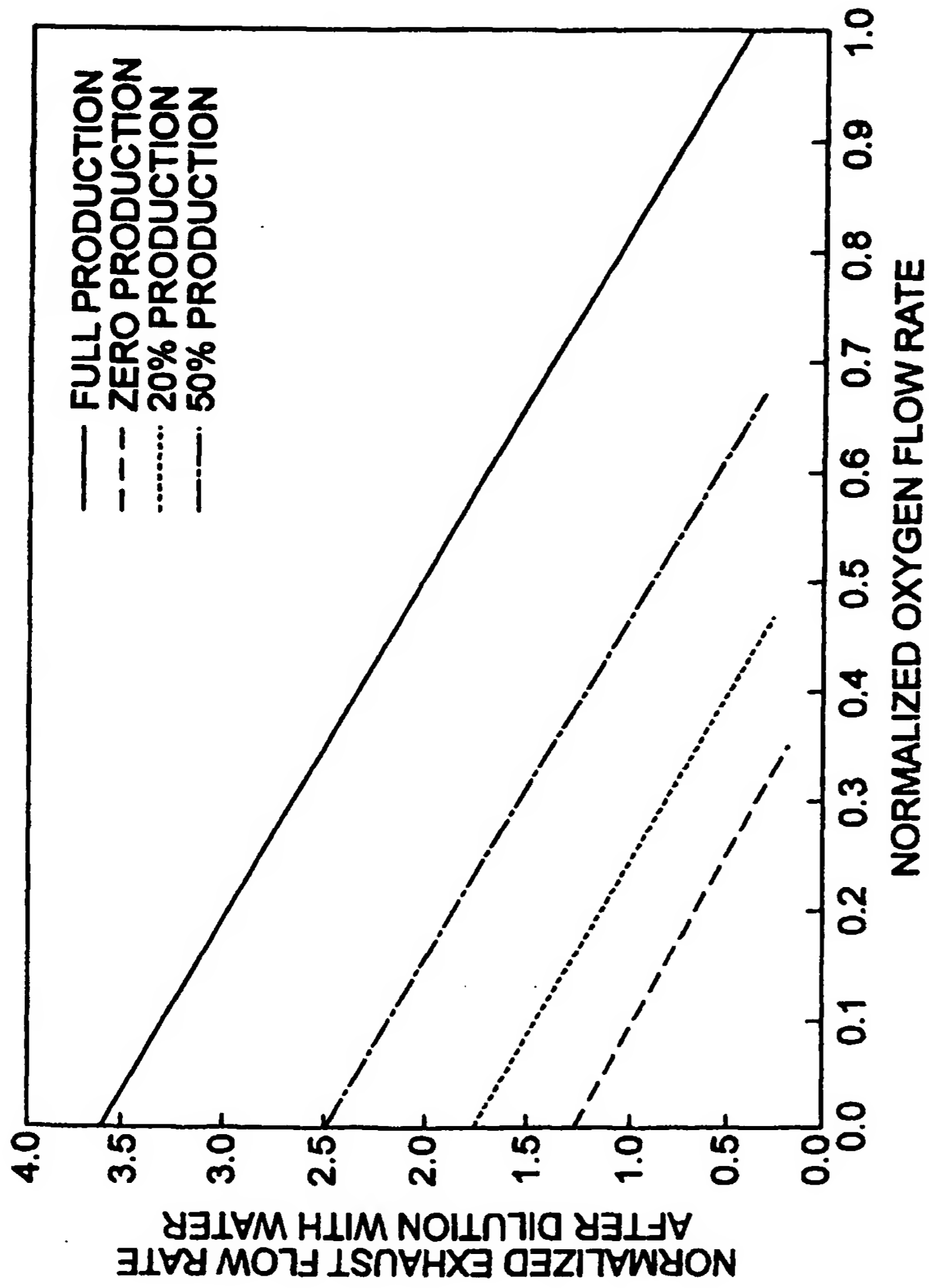


FIG. 8



**FIG. 9**



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# EUROPEAN SEARCH REPORT

Application Number  
EP 00 30 9081

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The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			F23D F23L C03B
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>24 January 2001</b>	Examiner <b>Coquau, S</b>
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